

# Field Release of the Parasitoid *Microplitis mediator* (Hymenoptera: Braconidae) for Control of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Cotton Fields in Northwestern China's Xinjiang Province

JIANCHENG LI,<sup>1,2</sup> FENGMING YAN,<sup>3,5</sup> THOMAS A. COUDRON,<sup>4</sup> WENLIANG PAN,<sup>2</sup>  
XIAOFENG ZHANG,<sup>2</sup> XIAOXIA LIU,<sup>1</sup> AND QINGWEN ZHANG<sup>1,5</sup>

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**ABSTRACT** Field experiments and surveys were conducted in 2003 and 2004 to evaluate the efficacy of using the parasitoid *Microplitis mediator* (Haliday) to control populations of *Helicoverpa armigera* (Hübner) in cotton fields in Northwestern China's Xinjiang Province. The population levels of the second generation of *H. armigera* in southern Xinjiang in 2003 and 2004 were  $\approx 20$ –60% above the economic threshold of this pest. The longevity of field-released female and male parasitoids was  $7.6 \pm 0.4$  and  $3.9 \pm 0.4$  d, respectively. Field tests showed that the number of parasitized *H. armigera* increased with an increasing number of *M. mediator* cocoons released in the field. The release of 2,250 or 15,000 laboratory-reared *M. mediator* cocoons per hectare in cotton fields resulted in 38–61% parasitism of *H. armigera* in 2003 and 35–66% parasitism in 2004. The efficiency of the parasitoids varied considerably with different numbers of parasitoid cocoons and with the frequency and sites of release. However, the highest damage reduction in these studies was obtained with a single release of cocoons and the highest number of release sites. Large-area releases of *M. mediator* in cotton fields of Shufu, Shule, and Shache counties resulted in  $>60\%$  parasitism and an 80% decrease in cotton boll and bud damage compared with the control fields. The above results indicated that field release of *M. mediator* could be used effectively in managing *H. armigera* in cotton in Xinjiang.

**KEY WORDS** *Microplitis mediator*, *Helicoverpa armigera*, mass rearing, field release, biological control

*Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), is the most destructive pest of economically important field crops in the Palaearctic region (Fitt 1989). In cotton, *H. armigera* larvae feed on foliage, flowers, buds, and bolls, causing severe yield losses if not controlled. In China, outbreaks of *H. armigera* in cotton fields can result in as much as a 30% reduction in yield. During years of heavy infestations of *H. armigera* in China, overall losses to cotton growers were estimated to be greater than \$100 million USD because of both yield losses and control expenses, including costs of insecticides and labor (Dai and Guo 1993).

Xinjiang is the largest cotton production area in China, and *H. armigera* is one of the most serious pests. Three generations of *H. armigera* occur each year in Xinjiang and the cotton yield losses mainly result from

damage by the second generation. The economic threshold of the second generation of *H. armigera* in Xinjiang is 35 eggs per 100 plants or 10–16 larvae per 100 plants (Li 1997). Unfortunately, as a result of intensive insecticide applications, *H. armigera* has developed resistance to nearly all classes of insecticides (Wu et al. 1997). According to the Xinjiang Government environmental regulations, current application of pesticides is rarely allowed. Consequently, biological control, including the release of natural enemies, could become a critical component of a more sustainable strategy for managing of *H. armigera* in Xinjiang cotton fields (Ma et al. 2000). Therefore, we targeted the second generation of this pest for biological control by parasitoids.

The solitary larval endoparasitoid *Microplitis mediator* (Haliday) (Hymenoptera: Braconidae), a Palaearctic species widely distributed in Europe and Asia (Arthur and Mason 1986), parasitizes larvae of  $\approx 40$  different lepidopteran species (Shenefelt 1973) and was the dominant parasitoid associated with *H. armigera* in China, comprising 58% of all larval parasitoids recovered from *H. armigera* in field collections in 1982 (Wang et al. 1984a) and parasitizing 22.9–40% of the *H. armigera* in the field. *M. mediator* can parasitize

<sup>1</sup> College of Agronomy and Biotechnology, China Agricultural University, Beijing 100094, China.

<sup>2</sup> Institute of Plant Protection, Hebei Academy of Agricultural and Forestry Sciences, Baoding, Hebei 071000, China.

<sup>3</sup> College of Life Sciences, Peking University, Beijing 100871, China.

<sup>4</sup> USDA–ARS, Biological Control of Insects Research Laboratory, Columbia, MO 65203–3535.

<sup>5</sup> Corresponding authors, e-mail: zhangqingwen@263.com; fmyan@pku.edu.cn.

first to fourth instars but prefers second and third instars to first and fourth instars (Wang et al. 1984a). These findings indicate that *M. mediator* has a good potential for the biological control of *H. armigera* if mass rearing for augmentative release were possible (Wang et al. 1984b, Li et al. 2004). Duration of *M. mediator* from egg to pupae is 7 d at 26°C (Li et al. 2005). The wasp has the longest adult longevity of  $15.4 \pm 0.4$  d for females and  $9.1 \pm 0.5$  d for males at 18°C with 10% honey water supply, and the shortest adult longevity of  $1.1 \pm 0.1$  and  $1.0 \pm 0.0$  d for females and males at 38°C with no food supply, respectively.

The first inundative field release trial of *M. mediator* to control *H. armigera* was conducted in Xinjiang cotton field in 2001 and consisted of one release level with one release time. However, many factors can influence the field performance of parasitoids, such as pest density, release timing, number and frequency of releases, and climate conditions (Lewis and Gross 1989, Hopper et al. 1991, van Giessen et al. 1993, Tillman 1996). Therefore, field experiments with more release levels and more release times were done in 2003 and 2004 to get more information (such as release numbers, frequency, sites) to evaluate the effectiveness of augmentative releases of this species for control of *H. armigera*. In this study, the population levels of *H. armigera* were monitored and the parasitization efficiency of mass-reared *M. mediator* in cotton fields was evaluated in Northwestern China's Xinjiang province.

## Materials and Methods

***Microplitis mediator* Mass Rearing.** *Mythimna (Leucania) separata* (Walker) (Lepidoptera: Noctuidae) was used as a host for mass rearing of *M. mediator* for these studies because *H. armigera* is cannibalistic, causing it to be more difficult to rear. *Mythimna separata* was obtained from a stock culture maintained by the Insect Natural Enemy Laboratory, Hebei Plant Protection Institute, Baoding. *M. separata* was reared on an artificial diet (Bi 1981) composed of a mixture of wheat germ and macerated leaf material from seedling corn and held at  $26 \pm 1^\circ\text{C}$  and 65% RH with L 14:D 10 photoperiod.

The colony of *M. mediator* was initiated from parasitoids that emerged from *H. armigera* larvae collected in cotton fields near Baoding, Hebei, during the late summer in 1998 and maintained on larvae of *M. separata*. Parasitization was accomplished by placing 50 2- to 4-d-old mated females of *M. mediator* in a cage (30 by 40 by 25 cm) containing 1,000 late first or second instars of *M. separata* with diet. After 12 h of exposure, host larvae were transferred to individual rearing bags containing artificial diet until the parasitoid cocoons formed. All rearing of the wasps was conducted at  $26 \pm 1^\circ\text{C}$  and 65% RH. Adult parasitoids were fed a solution of 10% commercial clover honey on cotton as a carbohydrate source. When reared in this manner, *M. mediator* achieved 85% parasitism on *M. separata* and a sex ratio of 1:1.2 (♀:♂). Cocoons were stored at

5–10°C for up to 15 d before use in field release studies and yielded  $\approx 93\%$  adult emergence.

Voucher specimens of *M. mediator* are deposited in the entomological collection at the Institute of Plant Protection, Hebei Academy of Agricultural and Forestry Sciences, China.

**Location of Experiments and Field Release Conditions.** A cotton field measuring 400 m long and 30 m wide in Baren Village, Shule County, Kashi City, Xinjiang Autonomous Region ( $39^\circ 30' \text{ N}$ ,  $76^\circ 10' \text{ E}$ ) was used for these studies. Cotton seeds (variety Yumian-15) were sown around 10–15 April in 2003 and 2004 at the density of 195,000 seeds/ha, and spacing of 60 cm between rows and 40 cm between plants was used. Experiments were conducted on plots located within the cotton field and isolated by a 1.5-m strip of rape-seed (*Brassica napus* L.) on each side, and alfalfa (*Medicago sativa* L.) bordered each end of the plot. Normal crop management, excluding pesticide application, was conducted as usual during parasitoid release, including fertilization and irrigation. Conditions during field experiments in late June and July included an average temperature of  $22.2^\circ\text{C}$  with a high of  $33.8^\circ\text{C}$  during the day and a low of  $12.4^\circ\text{C}$  at night, average relative humidity of 74.2%, and photoperiod of 14.5:9.5 (L:D) h.

**Population Levels of Second-generation *H. armigera* in Cotton Fields.** Three locations, close to the parasitoid release fields, in Shule county cotton fields were chosen to monitor the dynamics of *H. armigera* and to determine the best time of parasitoid release. The area of each location was  $\approx 6.67$  ha. Eggs and larvae of *H. armigera* were monitored daily from mid-June to the end of July in 2003 and 2004. Ten plants were sampled at each of 10 sampling sites at each location. The numbers of *H. armigera* larvae and eggs present on each cotton plant were recorded.

**Survivorship of *M. mediator* Adults in the Field.** In July 2004, observations of wasp survivorship in cotton fields were conducted under natural conditions in Xinjiang. Twenty female and 20 male adult wasps within 1 d of adult eclosion were used in field observations, and the test was replicated three times during the days when the field releases were conducted. Adult wasps were contained singly in cylindrical cages made of 60 mesh netting (20 cm in diameter and 35 cm in height). Each cage was hung on the cotton plant branch with or without living cotton plant twigs in the cage. The mortality of adult wasps was recorded daily, and the temperature and relative humidity in the field were also determined using a ZDR-20 Data Recorder (Zhejiang University Electric Equipment Factory, Hangzhou, China).

**Field Releases and Evaluation of Parasitism by *M. mediator*.** In southern Xinjiang, there are three generations of *H. armigera*, but only the second generation damages cotton; therefore, the second generation was the target for biological control by *M. mediator* in this study. Field releases of parasitoids were conducted in 2003 (on 3 July) and 2004 (on 10 July) when first instars of the second generation of *H. armigera* peaked in the fields. Before release, parasitoid cocoons

were taken from cold storage and held at 25°C for 2 d. A pyramid-form dispenser was used for field releases. The dispenser, a paper bag (5 by 8 cm) with a hole (2 cm in diameter) on one side for parasitoid adult emergence, was closed with a clip and attached to the cotton plant. The numbers of *M. mediator* cocoons in each dispenser varied for the different release levels and sites. Three days after releasing *M. mediator* in the field, at least 30 second and third instars of *H. armigera* were randomly collected from each plot, and percentage parasitism was determined. To determine whether collected larvae were parasitized, they were held singly in 15-ml clear glass tubes with cotton leaves until parasitoid cocoons formed or the host pupated.

**Effect of Number of Parasitoids Released, Frequency of Release, and Number of Release Sites on Parasitism Rates.** Field studies were conducted in 2003 and 2004 to evaluate the influence of numbers of parasitoids released on the extent of *H. armigera* parasitism and control and on boll damage. Releases of 2,250, 3,750, 4,500, 7,500, 10,500, 15,000 wasps/ha were replicated three times in 18 randomly chosen plots with each plot area of 1,800 m<sup>2</sup>. There were 10 m of cotton plants between the plots to serve as protection belts where no parasitoids were released. The control plots were located 1 km away from the treatment plots. The release of parasitoids and the collection of the *H. armigera* larvae after release were the same as described above.

To evaluate the influence of frequency of parasitoid releases when total release number of parasitoids was fixed, a single release of 4,500, 7,500, 10,500, or 15,000 parasitoids/ha was made on 8 July 2004, and two releases of 2,250 by 2, 3,750 by 2, 5,250 by 2, and 7,500 by 2 were made on 8 July and 15 July 2004. Three replicates were performed. The plot size, sampling, and release methods were the same as described above.

Two levels of *M. mediator* (7,500 and 15,000/ha) at 45, 75, and 105 sites/ha were used to evaluate the impact of the number of release sites on parasitism and damage reduction. The release sites were uniformly distributed in a grid with 10 m between locations. Three replicates were performed. The plot size, sampling, and release methods were the same as described above.

**Large-Scale Field Releases of *M. mediator*.** Large-scale field releases of parasitoids were conducted in 200-ha fields in June and July of 2001, 2003, and 2004 to evaluate the control efficacy of *M. mediator* when first-instar larvae of the second generation of *H. armigera* peaked in the fields. Only one release of 7,500 cocoons/ha was completed during 2001 (on 29 June) and two releases of 15,000 cocoons/ha were conducted in 2003 and 2004, on 3 and 8 July and 11 and 17 July, respectively. The area for large-scale releases were 25, 80, and 95 ha in Shufu, Shule, and Shache, respectively. Three days after each release, 50 second- and third-instar larvae of *H. armigera* were collected at each of five sampling locations in each plot. Five plots were sampled. The larvae were kept singly in 15-ml clear glass tubes with cotton leaves for 5–10 d until parasitoid cocoons formed or the host pupated,

and the proportion of parasitized larvae was determined.

**Determination of Parasitism and Damage Reduction.** The corrected proportion of *H. armigera* parasitism was obtained by the following formula: (proportion of parasitism in release plots – proportion of parasitism in control plots) / (1 – proportion of parasitism in control plots) × 100%. At the same time, the numbers of healthy and damaged bolls were also studied at 5 sampling sites × 10 plants within each plot 5 d after the release of parasitoids. Damage reduction (%) was expressed as (percentage of damaged bolls in control plots percentage of bolls in treatment plots) / (percentage of damaged bolls in control plots) × 100.

**Data Analysis.** Analyses were carried out using NCSS software package (Hintze 2001). Percentage data were arcsine transformed before analysis of variance (ANOVA) for determination of differences between treatments. Where significant differences at level of 0.05 occurred, Fisher least significant difference (LSD) multiple comparison tests were applied for mean separation.

## Results

**Population Levels of Second-generation *H. armigera* in Cotton Fields.** The dynamics of second-generation *H. armigera* in Xinjiang cotton fields in 2003 and 2004 are shown in Fig. 1. The second generation of *H. armigera* lasted for >1 mo, with peak larval populations occurring in early July of both years. The highest number of eggs and larvae recorded per 100 plants were 42 and 25, respectively, in 2003. Fewer eggs (34 per 100 plants) and larvae (17 per 100 plants) were found in 2004. The peak of the second larval generation occurred 5–7 d later in 2003 than in 2004.

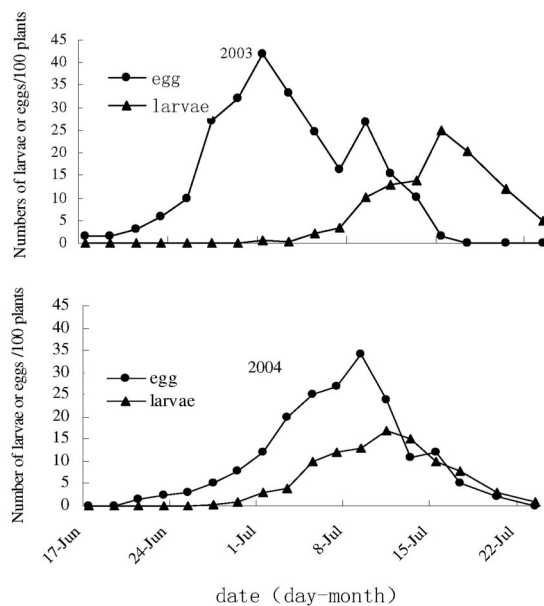


Fig. 1. Egg and larval population levels of second-generation *H. armigera* in Xinjiang cotton fields in 2003 and 2004.

Table 1. Adult longevity of *M. mediator* (means  $\pm$  SE) in cotton fields in Xinjiang Shule, July 8–25, 2004

Treatments	Temperature (°C)	Relative humidity (%)	Adult longevity (d)	
			Female	Male
No plants	15.7–33.8	48.5–84.2	7.6 $\pm$ 0.4 <sup>a</sup>	3.8 $\pm$ 0.2
With plants	14.3–31.5	53.3–92.3	5.2 $\pm$ 0.3	3.9 $\pm$ 0.4

No hosts were provided during the experiments. Means significantly different within a column (<sup>a</sup>  $P < 0.05$ ; Duncan's multiple range test).

**Survivorship of *M. mediator* in Cotton Fields.** Under field conditions, caged female *M. mediator* could survive for 7.6  $\pm$  0.4 or 5.2  $\pm$  0.3 d in cages with and without plants, respectively. By comparison, male survival was shorter, at 3.8  $\pm$  0.2 d when plants were absent from cages; this was not significantly altered with the presence of plants (Table 1). The cumulative mortality of parasitoids in the presence of plants reached 98.3% for male and 88.3% for female in 8 d. All parasitoids were dead in 10 d (Fig. 2).

**Effect of Number of Parasitoids Released, Frequency of Release, and Number of Release Sites on Parasitism Rates.** Results of field tests in 2003 and 2004 clearly indicated that parasitism increased, boll damage decreased, and damage reduction improved with increasing numbers of parasitoids released (Table 2). A single release of 7,500, 10,500, 15,000 parasitoids/ha resulted in parasitism rates of 45.2, 52.0, and 61.1%, respectively, which were significantly higher than the 38.7, 46.1, and 41.4% that resulted from single releases of 2,250, 3,750, and 4,500 parasitoids/ha ( $F = 67.80$ ;  $df = 5,12$ ;  $P < 0.05$ ). For boll damage and damage reduction, a single release of 15,000 parasitoids/ha performed the best, followed by 7,500 and 10,500 ( $F = 366.52$ ;  $df = 6,14$ ;  $P < 0.05$  and  $F = 123.12$ ;  $df = 5,12$ ;  $P < 0.05$ ). The data for 2004 (Table 3) was similar to that of 2003.

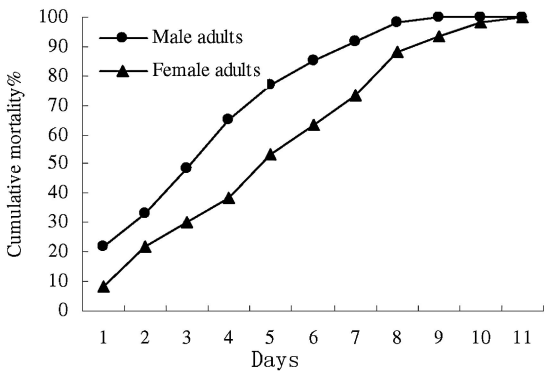


Fig. 2. The cumulative mortality of *M. mediator* wasps in cotton fields after the release days.

Table 2. Effect of no. of *M. mediator* applied in a single release on parasitism of *H. armigera* and on subsequent boll damage in cotton fields of Shule, Xinjiang, 2003

No. cocoons/ha	Parasitism (%)	Damaged cotton boll (%)	Damage reduction (%)
2,250	38.5 $\pm$ 1.0a	4.6 $\pm$ 0.2a	48.2 $\pm$ 2.1a
3,750	40.9 $\pm$ 1.4a	4.6 $\pm$ 0.2a	48.7 $\pm$ 2.3a
4,500	41.4 $\pm$ 0.5a	3.9 $\pm$ 0.1b	56.4 $\pm$ 1.8b
7,500	45.6 $\pm$ 1.3b	2.4 $\pm$ 0.1c	73.2 $\pm$ 1.3c
10,500	52.3 $\pm$ 1.0c	2.2 $\pm$ 0.1c	75.8 $\pm$ 0.5c
15,000	61.6 $\pm$ 0.9d	1.1 $\pm$ 0.0d	87.9 $\pm$ 0.3d
CK	—	8.9 $\pm$ 0.1e	—

*M. mediator* was released July 3 and the *H. armigera* larvae were collected July 6 for parasitism determination. Means  $\pm$  SE followed by the same letter within a column were not significantly different ( $P > 0.05$ ; Fisher's LSD multiple comparison tests).

For a set number of parasitoids, the damage reduction was better with a single release than with two releases (Table 4). For example, a one time release of 7,500 parasitoids/ha resulted in better parasitism and suppression than two releases of 3,750 parasitoids 7 d apart. However, two releases with double the number of parasitoids (e.g., 7,500 by 2) gave better control results than a one time release (e.g., 7,500 by 1).

When the number of release sites was increased, the damage reduction also increased (Table 5). When 7,500 parasitoids/ha were released at 75 and 105 release sites, the damage reduction was 51.1 and 55.1%, respectively, which were significantly higher than the damage reduction of 43.3% determined when the same number of parasitoids were released at 45 release sites ( $F = 15.03$ ;  $df = 5,12$ ;  $P < 0.05$ ). When 15,000 parasitoids/ha were released at 45, 75, and 105 release sites, the damage reduction was 57.8, 61.4, and 62.4%, respectively, which was significantly higher than that when 7,500 parasitoids/ha were released ( $F = 15.03$ ;  $df = 5,12$ ;  $P < 0.05$ ). However, the percentage of parasitism did not increase with the number of release sites when 15,000 parasitoids/ha were released.

Table 3. Effect of no. of *M. mediator* applied in a single release on parasitism of *H. armigera* and on subsequent boll damage in cotton fields of Shule, Xinjiang, 2004

No. cocoons/ha	Parasitism (%)	Damaged cotton boll (%)	Damage reduction (%)
2,250	34.8 $\pm$ 0.7a	4.2 $\pm$ 0.1a	57.9 $\pm$ 0.5a
3,750	39.5 $\pm$ 1.0b	3.9 $\pm$ 0.1ab	60.4 $\pm$ 4.4ab
4,500	43.9 $\pm$ 0.8c	3.7 $\pm$ 0.1b	63.1 $\pm$ 1.1b
7,500	48.0 $\pm$ 0.9d	3.0 $\pm$ 0.0c	69.3 $\pm$ 1.1c
10,500	56.6 $\pm$ 0.9e	1.9 $\pm$ 0.1d	80.4 $\pm$ 1.8d
15,000	65.6 $\pm$ 0.9f	1.1 $\pm$ 0.0e	88.5 $\pm$ 0.2e
CK	0.0 $\pm$ 0.0g	9.9 $\pm$ 0.3f	—

*M. mediator* was released July 10 and the *H. armigera* were collected July 17 for parasitism determination. Means  $\pm$  SE that are followed by the same letter within a column were not significantly different ( $P < 0.05$ ; Fisher's LSD multiple comparison tests).

Table 4. Effect of frequency of *M. mediator* release on the parasitism of *H. armigera* and subsequent *H. armigera* in cotton fields in Shule, Xinjing, 2004

No. cocoons/ha	Release frequency	Parasitism (%)	Damaged cotton boll (%)	Damage reduction (%)
4,500	1	39.9 ± 0.8a	3.0 ± 0.1a	71.8 ± 1.5a
7,500	1	47.5 ± 1.1b	2.4 ± 0.1b	78.0 ± 0.1b
10,500	1	56.7 ± 0.7c	1.9 ± 0.1c	82.4 ± 0.2c
15,000	1	63.3 ± 0.5d	1.2 ± 0.1d	89.4 ± 0.2d
2,250	2	34.3 ± 1.0e	4.6 ± 0.1e	58.9 ± 1.4e
3,750	2	39.0 ± 0.6a	4.0 ± 0.1f	62.4 ± 2.0e
5,250	2	46.0 ± 1.3b	2.6 ± 0.1b	77.1 ± 0.9b
7500	2	52.8 ± 0.9f	2.1 ± 0.1c	80.8 ± 1.5bc
Control	0	0.0 ± 0.0g	10.8 ± 0.3g	—

Data in the table are mean ± SE. Means followed by the same letter within a column were not significantly different ( $P < 0.05$ ; Fisher's LSD multiple comparison tests).

**Large-scale Releases of *M. mediator* for Control of *H. armigera* in Xinjiang Cotton Fields.** Large-scale field releases of parasitoids were conducted in Shufu, Shule, and Shache counties of Xinjiang to control *H. armigera* in 2001, 2003, and 2004 (Table 6). In 2001, a single release of 7,500 parasitoids/ha was applied to 25 ha, and the parasitism of *H. armigera* was 59.7% with a damage reduction of 80.4%. In 2003, two releases at rates of 15,000/ha at each release applied to 80 ha resulted in 60.9% parasitism of *H. armigera* and 85.3% damage reduction. In 2004, a single release of 15,000/ha applied to 95 ha resulted in 61.2% parasitism and 82.2% control effectiveness.

Discussion

Augmentative biological control, where large numbers of natural enemies are periodically introduced to control populations of pest insects, is commercially applied on a large area in various cropping systems worldwide (van Lenteren 2000). Recently, augmentative biological control has been used to manage pests that have become resistant to pesticides. As the prevalence of insecticide resistance increases, it is probable that efficacy and cost of augmentative methods will become comparable or superior to conventional chemical control. At that point, farmers are more likely to be motivated to use biological control to reduce environmental effects caused by pesticide use.

Pest control from inundative releases results mainly from the released natural enemies and not from their offspring. Inundative releases are often applied to crops where viable breeding populations of the natural enemy are not possible and in crops where the

Table 5. Effect of *M. mediator* release site numbers on the damage reduction to *H. armigera*. Shule, Xinjing Province, 2004.

Parasitoids/ha	No. sites	Parasitism (%)	Damaged bolls and buds (%)	Damage reduction (%)
7,500	45	43.3 ± 2.3a	3.3 ± 0.1a	66.4 ± 0.4a
7,500	75	51.1 ± 2.2b	2.6 ± 0.2b	76.2 ± 1.4b
7,500	105	55.1 ± 1.5bc	2.1 ± 0.1c	81.1 ± 1.4bcd
15,000	45	57.8 ± 1.4cd	2.1 ± 0.1c	79.1 ± 0.6bc
15,000	75	61.4 ± 2.2d	1.7 ± 0.1d	83.5 ± 1.3d
15,000	105	62.4 ± 1.0d	1.4 ± 0.1d	85.3 ± 1.3d
Control	0	0.0 ± 0.0e	9.8 ± 0.3e	—

Means ± SE followed by the same letter within a column were not significantly different ( $P > 0.05$ ; Fisher's LSD multiple comparison tests).

damage threshold is very low and rapid control is required at very early stages of infestation.

*Helicoverpa armigera* is one of the most serious pests of cotton in China, with populations that routinely surpass the economic threshold. Inundative releases of mass-reared *M. mediator* can lead to substantial reduction in cotton boll and flower damage by *H. armigera*, particularly in Xinjiang cotton fields. Releases are not as effective as conventional insecticide sprays that are able to reduce damage by >90%, but have proved to be consistent in integrated pest management (IPM) of cotton fields. The efficacy of *M. mediator* inundation, however, is dependent on correct handling of the parasitoids and a thorough understanding of the factors that can limit their performance under field conditions. Key aspects of *M. mediator* inundation that we have addressed through field trials are release rate, release frequency, release distribution, and survivorship under field conditions. From the 2-yr field release experiments reported here, we conclude that *M. mediator* can be an effective biological control agent for management of *H. armigera* in cotton in Xinjiang. Our results indicate that 7,500 parasitoids/ha resulted in better *H. armigera* control than lower release rates and that 7,500 parasitoids/ha is the most cost-effective application level because parasitism failed to increase at higher application rates. Similarly, at a level of 7,500 parasitoids/ha, the greater the number of release sites that was applied the better the control of *H. armigera*. However, when a higher level of 15,000 parasitoids/ha was applied, the number of release sites had no significant effect on *H. armigera* parasitism or boll damage, suggesting that the number of release sites becomes less important to *H. armigera* control when higher numbers of parasitoids are released.

The frequency of parasitoid releases will also impact parasitism of *H. armigera* and the incidence of plant

Table 6. Reduced damage resulting from releasing *M. mediator* in large area cotton fields

Year	Field location	Field size (ha)	Release numbers/ha	Release date	Release frequency	Parasitism (%)	Damage reduction (%)
2001	Shufu	25	7,500	June 29	1	59.7	80.4
2003	Shule	80	15,000	July 3, July 8	2	62.9	85.3
2004	Shache	95	15,000	July 10, July 17	2	61.2	82.2

damage. Although female parasitoids outlived male parasitoids in the field, female parasitoid survival after 10 d was low, implying that parasitoid populations in cotton fields will be affected by the frequency of parasitoid releases. Dry weather, little rain, and high temperature during daytime probably adversely affect the longevity and activity of the parasitoids. Laboratory experiments showed that parasitoid adult longevity was shortened as temperature increased (Li et al. 2005). Because female *M. mediator* survived for 1 wk if caged with plants, a weekly release may be frequent enough to ensure a continued population of parasitoids in the field. If the *H. armigera* population peaked in a 1-wk period, a single release may be enough to suppress the *H. armigera* populations below the economic threshold.

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